

Editorial

Taxonomic and ecological tradeoffs associated with small dam removals

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Dams and impoundments are widely recognized as having dramatic, negative impacts on freshwater ecosystems and are frequently implicated in the plight of endangered riverine biota (Dudgeon, 2000; Lydeard *et al.*, 2004; Strayer and Dudgeon, 2010; Burkhead, 2012; Haag and Williams, 2013). As such, their removal is a desirable and necessary component of stream restoration projects. Despite this general sentiment, there is a practical and financial need to prioritize among dams for removal and assess both the benefits and costs to stream ecosystems. Palmer *et al.* (2005) and others have called for standards to evaluate stream restoration success and specified five key traits of successful restoration projects. The first criterion they identified was that restoration must be guided by an image of a more dynamic, healthy river. Second, restoration should result in measurably improved stream condition and a more resilient self-sustaining system. Nearly all dam removal projects meet these criteria both inherently and quantitatively. In addition, Palmer *et al.* (2005) suggested that stream restoration should not cause irreparable harm to the ecosystem and that pre- and post-restoration monitoring data be made available to the public. While these may seem like eminently attainable and transparent goals, the reality is that financial restrictions limit the

temporal scale of pre- and post-removal monitoring and restrict the ability to describe recovery intervals accurately, which may in turn impede an accurate assessment of the long-term effects of dam removals.

Popular concepts of dam impacts are often focused, quite naturally, on their upstream effects on stream habitats. Dams transform free-flowing reaches to lentic habitats, restrict downstream sediment movement, and dramatically alter temperature, nutrient and productivity dynamics. Dams also alter downstream habitats and much work has documented physicochemical and biotic changes in downstream reaches. Much of what is known about dam impacts is derived from studies of high hydroelectric dams on large (i.e. >6th order) streams (Baxter, 1977; Graf, 2006). However, low-head dams (i.e. those <7.5 m height) greatly exceed hydroelectric dams in number and thus affect a much broader range of stream sizes and ecosystem types (Graf, 1999; Csiki and Rhodes, 2010).

Removing small dams has become a major part of stream and faunal restoration projects in North America. However, because so little is known about the effects of smaller dams on stream biota and ecosystems, obvious solutions may turn out to be problematic for other species. For example, because rivers across the globe have

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been highly altered by large dams, many endangered freshwater fish, molluscs and crustaceans are now restricted to tributary streams and small rivers (Dudgeon, 2000; Strayer and Dudgeon, 2010; Haag and Williams, 2013). Tributaries also have numerous dams but these tend to be small, run-of-the river structures. It is interesting that these dams are more economically and logistically appealing targets for stream restoration. Managers assume that all dams have similar negative effects but because of important hydrologic and geomorphic differences, their biotic and ecological effects may not be directly comparable with those of larger dams (Poff and Hart, 2002).

Here I argue that it is critically important to consider the potential negative and positive effects of removing small dams on both resident and migratory stream species. The majority of the published literature on dam removals has focused on effects on fish and mussels and I will rely heavily on this literature to make my case. Essentially, I am arguing for a more holistic and less dogmatically driven understanding of dams and the implications of dam removal on modern stream ecosystems and biota. A more complete understanding of issues related to barriers is simply critical to conservation and recovery of endangered taxa in impaired freshwater ecosystems. In this paper I will (1) examine literature describing some counter-intuitive effects of small dams, (2) assess the taxon-specific tradeoffs associated with removing small dams from stream ecosystems, and (3) compare tradeoffs associated with dam removal projects in Midwestern and south-eastern US streams. This editorial is intended to provide conservation researchers and resource managers with a different perspective on dams, and to identify and ultimately to evaluate better the potential effects of dam removals. Although this information is largely based on studies of North American streams, I believe they provide an important context for practitioners of dam removal in other regions.

LARGE VERSUS SMALL DAMS

Many studies have shown strong negative effects of large dams on lotic taxa. A wide range of riverine taxa including riparian zone plants (Merritt and Wohl, 2005), benthic insects (Lessard and Hayes, 2003), freshwater mussels (Blalock and Sickel, 1996;

Vaughn and Taylor, 1999; Lydeard *et al.*, 2004; Haag and Williams, 2013) and fishes (Burkhead, 2012; Liermann *et al.*, 2012) have been directly extirpated or dramatically fragmented by large dams. The primary mechanisms associated with these adverse effects include greatly altered water temperature, hydrologic regime and geomorphology triggered by reservoir stratification, hydropower generation schedules and sediment retention (Graf, 1999, 2006). Dam removal has been widely prescribed as a remedy for these ills.

Effects of small dams are generally believed to mirror those of larger dams. Surprisingly, however, a growing body of evidence suggests that low-head (<7.5 m), run-of-the-river dams may have unanticipated positive effects on downstream habitat and biota. This phenomenon was perhaps first noted by Walter (1956) who found that in highly degraded Neuse River Basin (North Carolina, USA) streams, freshwater mussel assemblages were more species-rich downstream of small impoundments than in other parts of this catchment. He speculated that dam spillways may have provided a key source of re-oxygenation for nutrient-enriched waters and helped maintain populations of these sensitive organisms in highly degraded (pre-US Clean Water Act) streams. More recent (and quantitative) studies in Alabama and North Carolina showed that mussel populations are more temporally persistent immediately downstream of small dams (Gangloff *et al.*, 2011), more abundant and diverse (McCormick, 2012), attain larger sizes and grow faster than do conspecifics in populations further upstream or downstream (Singer and Gangloff, 2011; Hoch, 2012).

Earlier studies purporting to show negative effects of small dams on fish and mussels used largely qualitative data or found effects primarily by comparing impounded to free-flowing reaches (Watters, 1996; Dean *et al.*, 2002; Tiemann *et al.*, 2004, 2007). Although all of these studies found that mussels were largely absent from impoundments, they provided no comparisons with sites in true upstream control reaches (i.e. not influenced by dams) or nearby un-dammed streams. As such, these studies do not provide spatially or statistically rigorous contexts for assessing the broader effects of small dams on impaired streams or sensitive lotic biota.

OTHER BENEFITS OF BARRIERS

Invasive species are widely recognized as one of the chief threats to freshwater (and global) biodiversity (Lydeard *et al.*, 2004; Strayer and Dudgeon, 2010). To managers concerned with invasive species, increased connectivity of linear ecosystems may not always be a desirable goal. Jackson and Pringle (2010) provide an excellent, if counter-intuitive review of the management benefits of decreased hydrologic connectivity including reduced movement of exotic species (Kerby *et al.*, 2005). Dams have long been a component of invasive fish management strategies beginning with sea lamprey control in Laurentian Great Lake tributaries (McLaughlin *et al.*, 2012). Dams continue to be important barriers to invasive apex predators such as flathead catfish (*Pylodictis olivaris*) in the Tar River (NC) and across the south-eastern USA, and nuisance fishes such as bighead and silver carp and sea lamprey (*Petromyzon marinus*) in the Great Lake and Mississippi River basins (Pine *et al.*, 2007; Jackson and Pringle, 2010; McLaughlin *et al.*, 2012; Gangloff *et al.*, unpublished data). Small dams may be important mimics of historically abundant barriers including beaver dams and woody debris jams that once provided important structure, habitat heterogeneity and prey resources that were important to fish productivity and communities (Naiman *et al.*, 1988; Snodgrass and Meffe, 1998; Benke and Wallace, 2003).

CASE STUDIES

Palmer *et al.* (2005) noted that extensive pre- and post-restoration monitoring are uncommon, seldom published in peer-reviewed journals and easily the least frequently met of their five restoration criteria. Recently, however, agencies require more extensive monitoring and two regions of the USA have excellent records of quantifying ecological costs and benefits of dam removal. The upper Midwest/Great Lakes region has seen a tremendous increase in the frequency of dam removals as a result of increased interest in fish passage and stream restoration associated with large-scale ecosystem rehabilitation programmes such as the Great Lakes Restoration Initiative

(Januchowski-Hartley *et al.*, 2013). Dams in many Atlantic Slope streams have also been increasingly targeted for removal to improve anadromous fish passage (Burdick and Hightower, 2006; Hitt *et al.*, 2012). Moreover, in some states, stream mitigation banking provides an important financial incentive to private landowners, corporations and municipalities to remove dams (Doyle and Shields, 2012).

Studies from upper Mississippi/Great Lakes tributaries and the south-eastern USA provide an interesting contrast in approaches to dam removal priorities and methodology with similar rates of success. Numerous dams have been removed in these regions, primarily to improve fish passage and access to spawning habitat. Although removal of some dams has improved riverine fish passage and occupied habitat (Kanehl *et al.*, 1997; Burdick and Hightower, 2006; Catalano *et al.*, 2007) other studies have indicated more equivocal results of dam removals on fish populations or communities (Stanley *et al.*, 2007; Maloney *et al.*, 2008). Both regions have abundant agriculture, and catchment land-use probably influences unanticipated effects of dam removal via nutrient and sediment mobilization rates. However, to date no studies have looked at how catchment or local land-use affects the success of dam removals in restoring natural stream functioning or biological communities.

Early dam removals were dramatic affairs and often involved rapid de-watering or demolition of instream structures (Doyle *et al.*, 2003). Sethi *et al.* (2004) followed the effects of one such dam demolition on downstream habitats and freshwater mussels in Koshkonong Creek, Wisconsin. In their study, sediments from the impoundment were rapidly transferred downstream and smothered mussel beds thereby causing what some managers might see as irreparable harm to the ecosystem. Results of this relatively controlled study mirror museum and field data suggesting that historical (and probably also catastrophic) dam failures are likely to have contributed to freshwater mussel extirpations across the south-eastern USA. For example, Gangloff *et al.* (2011) found that Alabama streams with breached dams had lost a higher proportion of mussel species than nearby streams

with intact dams. McCormick (2012) similarly noted that North Carolina streams with partially or completely breached dams support lower mussel density and species richness compared with nearby streams or reaches with intact dams (Gangloff *et al.*, 2011; McCormick, 2012). Many of these dams had been in place for decades, if not centuries, and streams had most likely adjusted geomorphically and biologically to impounded conditions. This is critical to understand because although biota in streams with uncontrolled dam breaches will probably recover from the disturbance, recovery rates will depend on the dispersal ability, growth rate and fecundity of biota. Unregulated partial or complete dam breaching may greatly exacerbate downstream channel bed scour and have dramatic negative consequences for sedentary downstream biota (Sethi *et al.*, 2004; Gangloff *et al.*, 2011; McCormick, 2012). Habitats disturbed by uncontrolled dam breaches also have decreased fish abundance and richness (Helms *et al.*, 2011; Gangloff, unpublished data) and may be more suitable for exotic fishes (Thoni *et al.*, unpublished data).

Conversely, Heise *et al.* (2013) found that controlled demolition of a small North Carolina dam on the Little River (Pee Dee River Drainage) had little or no effect on downstream mussel populations. Other recent studies show that controlled dam deconstructions appear to minimize adverse effects on mussel populations. McCormick (2012) surveyed mussel populations upstream and downstream of two small dams, Cherry Hospital and Lowes Mill that were removed from the Little River, a tributary of the Neuse River in North Carolina, to improve the passage of river herring and American shad (*Alosa sapidissima*) (Burdick and Hightower, 2006). Mussel assemblage data revealed few differences upstream and downstream of both former dam sites. These data suggest that controlled removal of small dams does not necessarily impair downstream mussel populations provided that removal is conducted in a deliberate manner. However, it should be noted that no data are currently available describing how mussel assemblages respond over long durations to habitat and ecosystem changes associated with controlled dam removals.

IMPLICATIONS FOR MANAGEMENT AND RESTORATION

Some US states have begun aggressively removing low-head dams and restoring stream habitats. American Rivers, the American Fisheries Society, the Nature Conservancy, and Trout Unlimited among numerous other conservation groups broadly advocate dam removal, but these activities are largely confined to North America. Accounts of low-head dam removal on other continents are scarce. The majority of dam issues in the developing world involve construction (Dudgeon, 2000). Many agencies and researchers have begun to devise prioritization metrics for dam removals. These project goals frequently include restoration of diadromous fishes but just as frequently ignore effects on other stream organisms (in particular effects associated with increasing stream access to invasive or non-native game fishes). In addition, managers content to let failing or breached dams become degraded are operating with the erroneous assumption that passage in any form is beneficial. Increasingly, evidence suggests that the technological obsolescence and abandonment of many small dams may have profound ecological implications in the long term that may ultimately require more hands-on management. Although intact small dams are relatively easy and inexpensive to remove, removal of breached small dams can be even more cost-effective. Removal of breached dams should rank as high as or higher than removal of intact dams in many of the south-eastern drainages that I have studied.

One final point: the increasing popularity of mitigation banking has been driven in large part by the substantial profits derived from removing dams and restoring streams to their natural states, and the development of this industry has proceeded largely without comment from the aquatic ecology community. This is problematic for several reasons. First, as noted above, potentially beneficial effects of small impoundments are often unknown (if not anathema) to conservation practitioners. Second, in today's anthropogenically-influenced streams, small dams and their impoundments may perform critical ecological functions including filtering and de-toxifying anthropogenically elevated nutrient loads, oxygenating low-gradient streams during

low-water periods and stabilizing stream beds critical to the persistence of endangered freshwater fish and mollusc taxa. Impoundments may also retain fine sediments and associated toxins, impede the spread of invasive species, and help attenuate floods from urban or highly agrarian basins (Fairchild and Velinsky, 2006; Jackson and Pringle, 2010).

Taken together these services may, in some instances, far outweigh the benefits of dam removal and suggest that in extreme cases a prudent inaction (i.e. leaving or maintaining small dams) may prove beneficial to endangered mussels and other resident stream biota. A mounting body of evidence suggests that, in the right context, retention of beneficial small dams may be a key and not necessarily artificial stepping-stone to more meaningful, catchment-scale ecosystem restoration. Ultimately, the goal of complete catchment restoration is a noble one but it may also prove to be impossible if haphazard removal of barriers degrades habitats and eliminates sensitive resident taxa. In approaching dam removals, we would be wise to remember Leopold's (1949) exhortation that to keep every cog and wheel is the first rule of intelligent tinkering. I think that in these troubled environmental times this must apply to some obvious sources of impairment including small dams. Balancing the diverse and frequently competing taxonomic objectives of modern stream restoration will require a more holistic understanding of the nexus between barriers, land use and biota and of the realization that there are few easy answers in aquatic conservation biology.

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